Measurement of Aerosol Shortwave Direct Forcing At the ARM SGP Site

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ABSTRACT

Scattering of shortwave (solar) radiation by aerosols is thought to exert an influence on the earth's radiation budget that is comparable in global and annual average magnitude to the enhanced absorption of longwave (thermal infrared) radiation due to increased concentrations of greenhouse gases, and substantially greater locally and for short time periods. Although aerosol optical depth is readily measured from the surface, measurement of aerosol influence on shortwave irradiance, either at the surface or at the top of the atmosphere (TOA), is more problematic. Here we use measurements of downwelling direct-beam and diffuse sky irradiance under cloud-free conditions to determine the aerosol contributions to these components of the radiation budget. The difference between the measured downwelling irradiance and that calculated for identical atmospheric conditions in the absence of aerosol, the aerosol forcing of surface irradiance, can be directly related to the measured aerosol optical depth. Because the aerosol influence on the surface radiation budget is nearly complementary to the influence on net TOA irradiance, it may be possible to use the surface measurements to infer the latter quantity with high accuracy.

Background

Aerosols scatter and absorb shortwave (solar) radiation. (This is aerosol ***direct*** forcing, as distinguished from ***indirect*** forcing involving clouds.)

Direct shortwave radiative forcing at the top of the atmosphere (TOA) by anthropogenic aerosols is thought to be comparable in magnitude (opposite in sign) to longwave forcing by anthropogenic greenhouse gases globally and substantially greater locally and for short time periods.

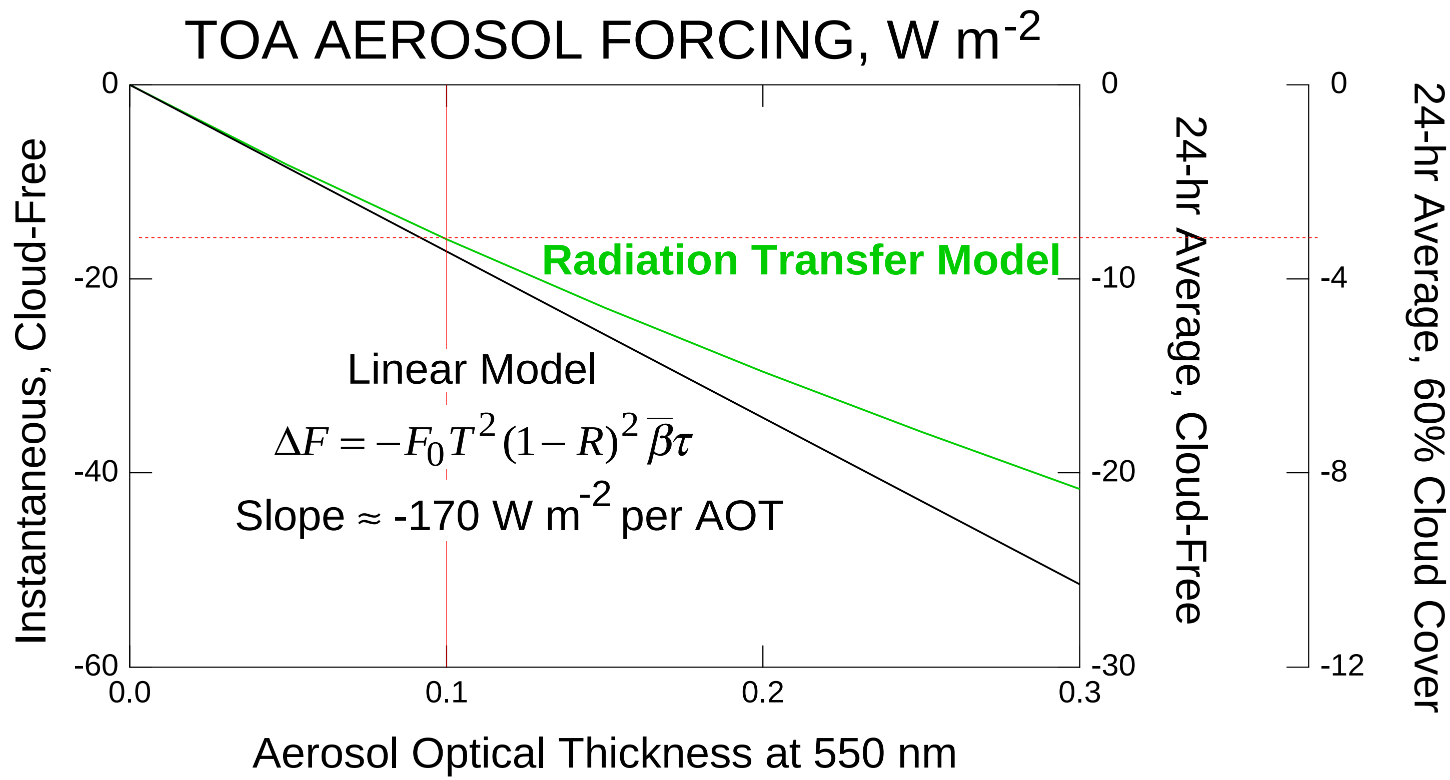
Aerosol optical depth is readily measured from the surface, measurement of aerosol influence on shortwave irradiance, either at the surface or at the top of the atmosphere (TOA), is more problematic.

DIRECT AEROSOL FORCING AT TOP OF ATMOSPHERE

Dependence on Aerosol Optical Thickness

Comparison of Linear Formula and Radiation Transfer Model

Particle radius r = 85 nm; surface reflectance R = 0.15; single scatter albedo ω_0 = 1.



Global-average AOT 0.1 corresponds to global-average forcing -3.2 W m^{-2}.

Approach

Here we use measurements of downwelling **direct** and **diffuse** irradiance ***under cloud-free conditions*** to determine the aerosol contributions to these components of the radiation budget.

The aerosol forcing of surface irradiance is measured as the difference between the measured downwelling irradiance and that calculated for identical atmospheric conditions in the absence of aerosol (Rayleigh atmosphere).

The measured aerosol forcing can be related to measured aerosol optical depth and other aerosol properties.

MEASUREMENT OF **DIRECT**, **DIFFUSE**, AND **TOTAL** AERosol DIRECT FORCING OF SURFACE IRRADIANCE

- Aerosol direct forcing is difference between surface irradiance with and without aerosol.

- For cloud-free, aerosol-free (Rayleigh) atmosphere, surface irradiance is ***calculated*** (**direct** and **diffuse** components) for specified illumination geometry, surface reflectance.

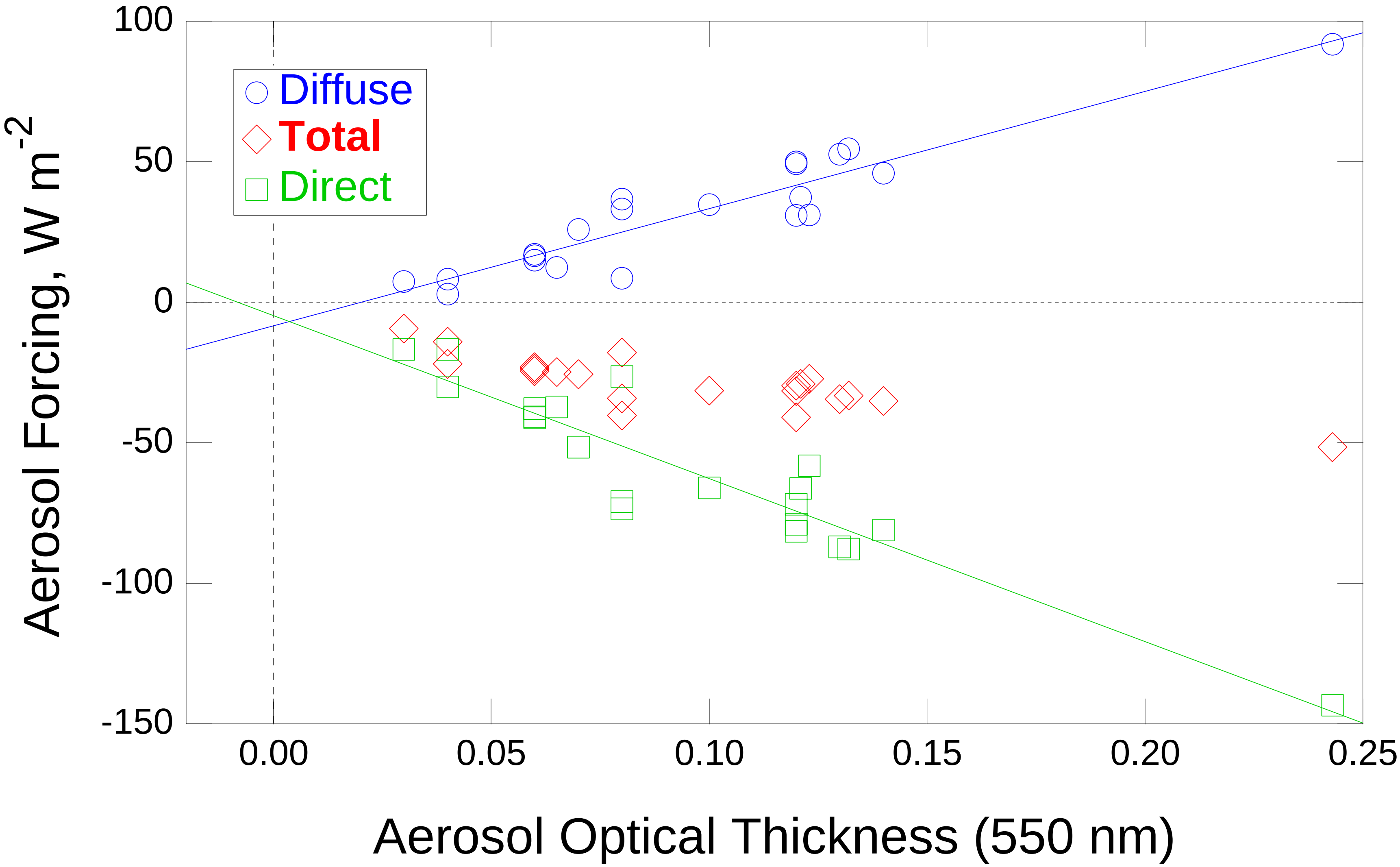
- Surface irradiance is ***measured*** (**direct** and **diffuse** components) in the presence of aerosol of measured optical thickness (sun photometry), for cloud-free sky.

- Direct Aerosol Forcing is ***measured*** (**direct** and **diffuse** components) as function of aerosol optical thickness as the difference between measurement and Rayleigh calculation.

AEROSOL FORCING OF SURFACE IRRADIANCE

Dependence on Aerosol Optical Thickness

Cloud-free sky, DOE ARM Site, North Central Oklahoma



Aerosol scattering **decreases direct** irradiance, **increases diffuse** irradiance.

Aerosols **decrease total surface irradiance (direct + diffuse)** mainly because of upward scattering (top-of-atmosphere forcing) and to lesser extent enhanced atmospheric absorption.

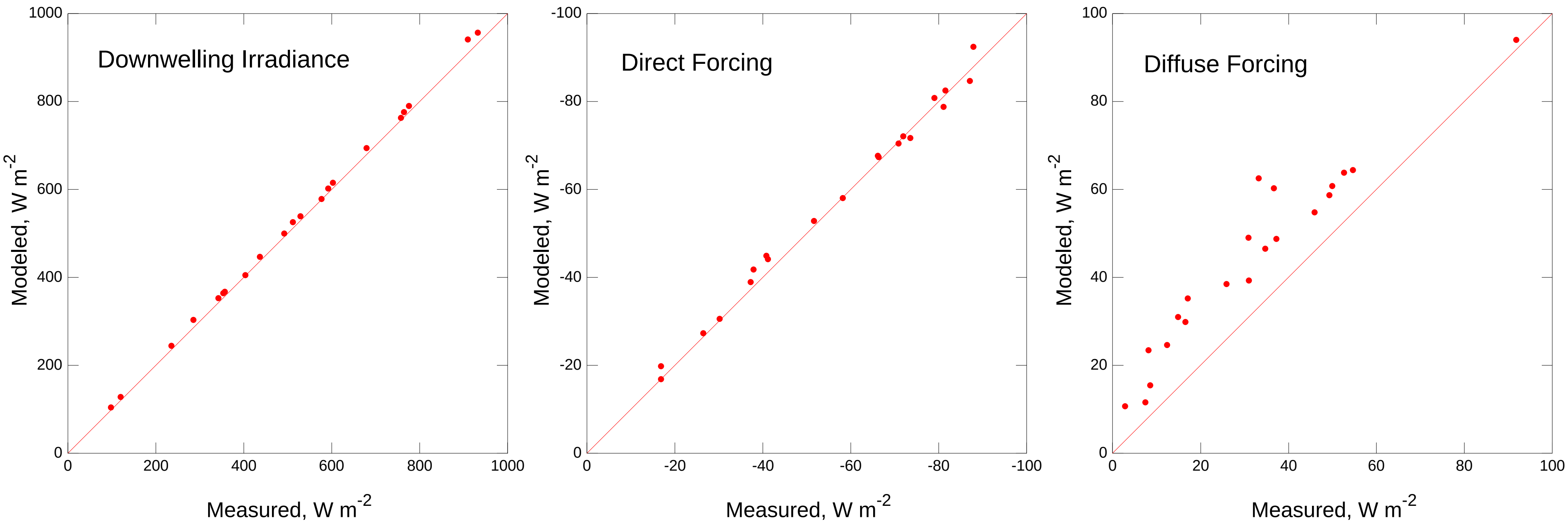
Direct forcing is proportional to aerosol optical thickness determined from sun photometry.

Diffuse forcing intercept corresponds to excess optical thickness of 0.02, consistent with earlier work

AEROSOL FORCING OF SURFACE IRRADIANCE

Comparison with Radiation Transfer Model

Cloud-free sky, DOE ARM Site, North Central Oklahoma



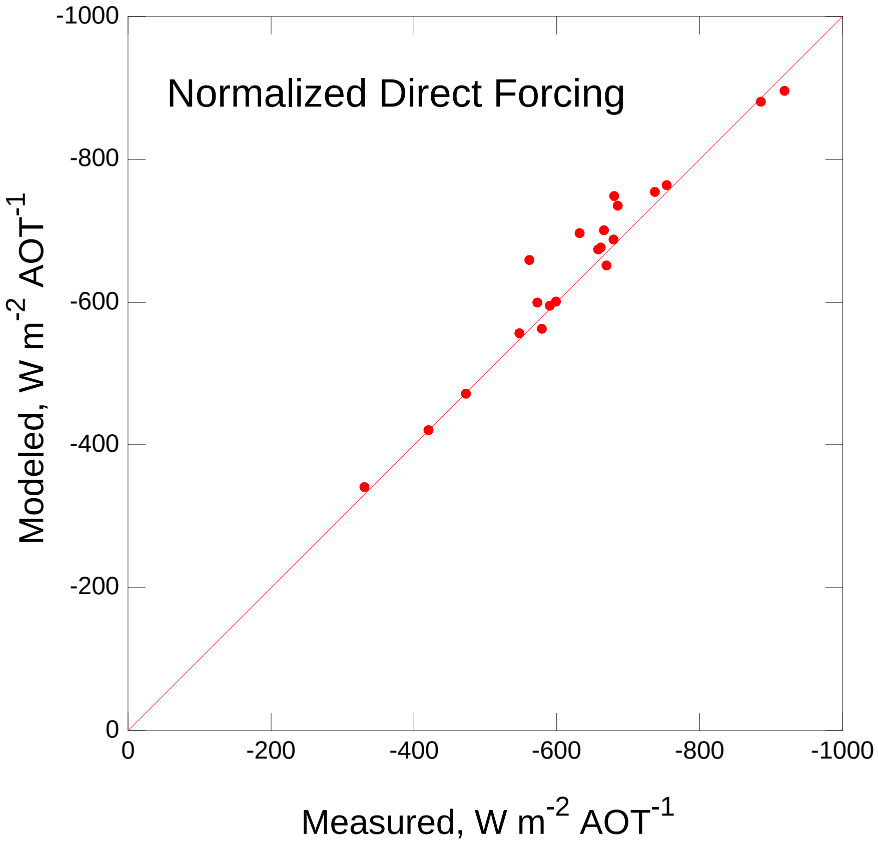
Note systematic discrepancy in diffuse forcing, as revealed also in Halthore *et al*. (*GRL*, 1998) and Halthore and Schwartz (*JGR*, submitted, 1999).

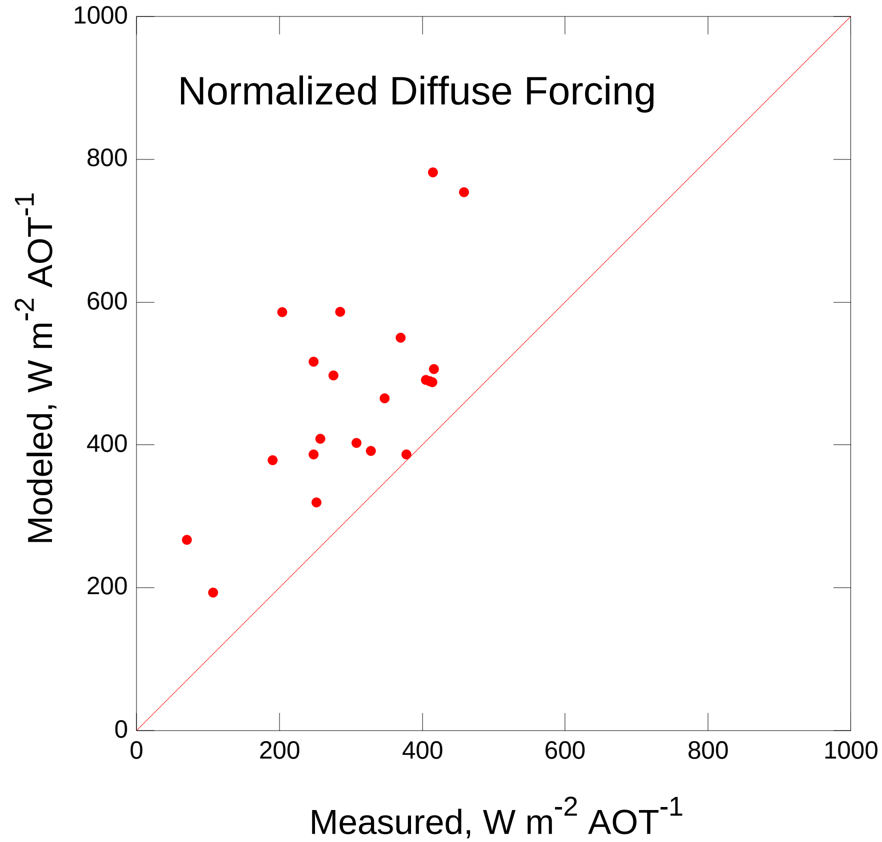
AEROSOL FORCING OF SURFACE IRRADIANCE

NORMALIZED TO AEROSOL OPTICAL THICKNESS

Comparison with Radiation Transfer Model

Cloud-free sky, DOE ARM Site, North Central Oklahoma





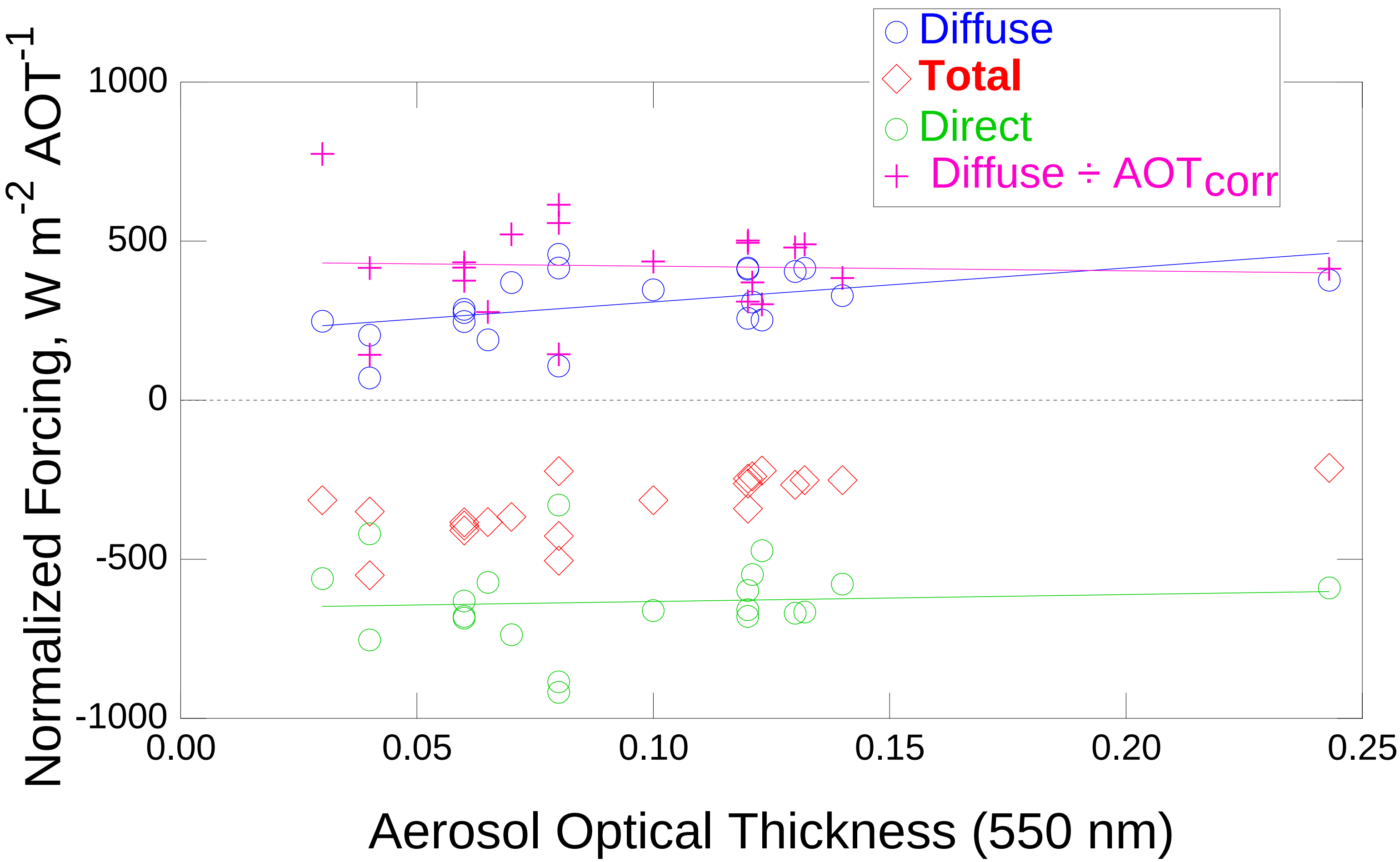
Again note systematic discrepancy in diffuse forcing.

AEROSOL FORCING OF SURFACE IRRADIANCE

NORMALIZED TO AEROSOL OPTICAL THICKNESS

Dependence on Aerosol Optical Thickness

Cloud-free sky, DOE ARM Site, North Central Oklahoma



Normalized direct forcing is independent of AOT.

Normalized diffuse forcing falls off at low AOT because of "diffuse discrepancy".

With AOT "corrected" by 0.02, normalized diffuse irradiance is independent of AOT.

Conclusions

- Surface aerosol direct forcing can be readily and accurately measured.
- Surface aerosol forcing is substantial in the context of magnitudes of forcing associated with greenhouse gas forcing.
- Surface aerosol forcing may substantially influence surface heating, evaporation and evapotranspiration, and photosynthesis.
- Surface aerosol forcing can readily be related to concurrently measured aerosol properties.
- The discrepancy between modeled and measured diffuse irradiance urgently needs to be resolved.
- Surface aerosol forcing offers the hope (not yet fulfilled) of a low-uncertainty route to TOA forcing.